TO DESIGN RAINWATER COLLECTION SYSTEM FOR DOMESTIC USE AND THE ECONOMIC COST ANALYSIS OF THE SYSTEM

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ABSTRACT

This thesis deals with the design of the rainwater collection system for domestic use and economic cost analysis of the system. The objective of this thesis are to design rainwater collection system and analyze the economic cost of the system for a family Pekan people. Rainwater are a natural source of clean water and suitable for non-portable use and solve the water shortage problem In this study, parameters of quality of rainwater were measured such as pH, turbidity, dissolve oxygen and total suspended solid. The finite element analysis was then performed using the software of Algor Simulation. The type of analysis was static stress with linear material model analysis against the structure stand of rainwater storage tank. The annual rainfall data of 2012 will be analyzed by software of Tanki Norm Simulation to find out the reliability of the rainwater collection system. In the result, all parameters of quality of rainwater measured were acceptable by refer from the table shown by Interim National Water Quality Standards For Malaysia (Class IIB) except the level of dissolved oxygen was quite low compare with it. From the result of Tanki Nahrim Simulation, shown that the reliability of the system was 61.23 %. In economic aspect, it found out that the rainwater cost RM 3.1 per meter cube with five year payback period of the system which is higher than RM 0.37 per meter cube of pipe water.

ABSTRAK

Tesis ini membentangkan tentang reka bentuk sistem pengumpulan air hujan untuk kegunaan domestik dan analisis kos ekonomi sistem. Objektif projek ini adalah untuk mereka bentuk sistem pengumpulan air hujan dan menganalisis kos ekonomi sistem bagi keluarga Pekan. Air hujan adalah sumber semula jadi air bersih dan sesuai untuk kegunaan bukan mudah alih dan menyelesaikan masalah kesutukan air Dalam kajian ini, parameter kualiti air hujan diukur seperti pH, kekeruhan, kelarutan oksigen dan jumlah pepejal terampai. Analisis unsur terhingga dilakukan dengan menggunakan perisian Algor Simulasi. Jenis-jenis analisis adalah tekanan statik dengan model linear analisis bahan terhadap strukur untuk tangki simpanan air hujan. Data hujan tahunan 2012 akan dianalisis oleh perisian Tanki Norm Simulasi untuk mengetahui kebolehpercayaan sistem pengumpulan air hujan. Dalam keputusan ini, semua parameter kualiti air hujan yang diukur boleh diterima oleh Interim National Standard Kualiti Air Untuk Malaysia (Kelas IIB) jika rujuk jadual yang disediakannya kecuali tahap oksigen terlarut adalah agak rendah berbanding dengan standardnya. Dari hasil Tanki NAHRIM Simulasi, menunjukkan bahawa kebolehpercayaan sistem ini adalah 61.23%. Untuk ekonomi aspek, ia didapati bahawa kos air hujan adalah RM 3.1 per meter padu untuk tempoh lima tahun bayaran balik sistem dan harga ini adalah lebih tinggi daripada RM 0.37 setiap meter padu air paip.

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LIST OF SYMBOLS

Q_t	Volume of rainwater collected
φ	Runoff coefficient
R_t	Rainfall
A	Overall collected surface area
V_{avg}	Average flow velocity
D	Characteristic length of the geometry
v	Kinematic viscosity of the fluid
μ	Dynamic Viscosity
ρ	Density of fluid
$h_{L,total}$	Total head loss
$h_{L,major}$	Major head loss
$h_{L,\min or}$	Minor head loss
$h_{L,pump}$	Head loss pump
$h_{L,turbine}$	Head loss turbine
L	Length pipe
f	Darcy friction factor
K_L	Fluid flow velocity
g	Acceleration of gravity
z	Elevation

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
DO	Dissolved Oxygen
FEM	Finite Element Method
FKM	Faculty of Mechanical Engineering
LCD	Liquid Crystal Display
MIG	Metal Inert Gas
PIC	Peripheral Interface Controller
TSS	Total Suspended Solid
UMP	University Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Water is an important source for every living organism, human and plant need water for survival. Water is a nature's gift given to the mankind living on the earth. However, the shortage of water supply had become a global issue. The enlargement of the population of the worldwide had lead to increase the water's demand. In addition, develop country try to keep pace with the rapid growth of the country's economy and discharge chemical, solid, rubbish to the river, squatter, land development, slaughter houses, improperly dispose waste from animal husbandries and firms had caused the water pollution problem. The additional of the chemical such as chlorine for water treatment process will kill all the bacteria and micro-organisms include the useful micro-organisms contain the water. To solve the problem of shortage of water supply, water collected by a rainwater collection system is the best solution and alternation for the region. Malaysia is a suitable place to build the rainwater collection system due to its located near the Equator and received annual rainfall 990billion m^3. Peninsular Malaysia annual rainfall averaging 2400 mm; Sabah is averaging 2300 mm; Sarawak is averaging 3800mm. (Department of Irrigation and Drainage Malaysia). By 1998 drought, Malaysia was introduced to build the rainwater harvesting system following by the "Guidelines for Installing a Rainwater Collection and Utilization System" and aim to reducing the water treatment requirement and water act as times of emergency or a shortfall in the water supply.

Rain water had become a main natural source of water supply in non-potable and portable used. The non-potable rain water was generally used in washing floor, flushing toilet and watering garden. The potable used of the rainwater was included cooking, drinking, washing dish and bathing. The rain water could be collected from the roof and open area. The size of the catchment of the rainwater collection system is depended of the roof area and the demand. For large catchment, the collection of rainwater could be from the roof area of educational institutional, industrial and other whereas the collection of rain water from the roof area of houses and small size building was for small size system.

1.2 PROBLEM STATEMENT

Shortage and cleanliness of water supply problem are always found to be a concern in Pekan. Therefore, Rainwater is an alternative source of water supply in time of shortage of water and provide clean natural water for use in domestic. A rainwater collection system needed to be designed and to be used in non-portable used.

1.3 OBJECTIVE OF STUDY

i. To design rainwater collection system.
ii. To analyze the economic cost of the system for a family Pekan people.

1.4 SCOPE OF STUDY

One of the buildings on the pekan campus would be selected for a rainwater collection system. 300 US standard gallon of storage capacity tank collects the rainwater from the rooftop of the building. Rainwater collected is used for non-potable proposed. Cost analysis of the system is performed.

1.5 SIGNIFICANT OF STUDY

Rain water collected will act as alternative source of water supply which is clean and minimum maintenance cost.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Water plays a major role in laying the foundation for economic growth, not only by increasing the assurance of supply, but also by improving water quality and therefore human health (Phillips et al., 2006). Since independence in 1957, Malaysia has keeped the pace to improve the social and economic standing of the country and her people. These improvements included health care system together with access to quality water, sanitation and nutrition.(The State of the World's Children 2011). Although the water quality supply system has been improved, the demand is increase following the growth of the population and development. The climate changed and causes dry period also be a factor in increasing the demand of water supply.

Che-Ani et al., (2009) stated that Malaysia has a few cities which have high density population such as Lambah Klang, Pulau Pinang and Johor Bahru. These cities required high water supply demand than other cities in Malaysia. In 1998, Malaysia facing a serious water crisis especially in Lembah Klang this is due to climate changes (Shaari et al., 2009). After the water crisis 1998, Malaysian Government has introduced to build rainwater harvesting system following the "Guidelines for Installing a Rainwater Collection and Utilization System" (Mohd. Shahwahid et al., 2007).

Rainwater harvesting seems to be a beneficial method for minimizing water scarcity in developing countries (Helmreich and Horn, 2008). Clean rainwater collected not only solved the water crisis problem but also reduce the water treatment cost. There are two categories of storage reservoirs, surface or aboveground tanks (common for roof collection) and sub-surface or underground tanks (common for ground catchment systems) (Kahinda et al.,2007). Size of storage tank depends on the requirement but the local rainfall characteristics throughout the non winter season also affect the size required and the reliability of a storage unit to supply water when needed (Guo and Baetz, 2007).

2.2 AMOUNT OF RAINFALL FORECASTING IN PAHANG, PEKAN

Table 2.1 represented the mean of the total precipitation anomalies, that is the differences between predicted precipitation and the long-term mean precipitation, for three-monthly periods; September-October-November, October-November-December, and December-January-February respectively, from the European Centre for the Medium-Range Weather Forecast (ECMWF) seasonal forecast model.

Table 2.1: Amount of rainfall forecasting in three monthly periods of September 20 to February 2013

State		Monthly Rainfall Amount (mm) Forecast	Period	Weather Outlook in terms of Rainfall
Pahang	Kuantan, Pekan, Rompin	120 – 260	September	Average
		170 – 330	October	Average
		220 – 430	November	Average
		330 – 740	December	Average
		200 - 380	January	Average
		100 - 190	February	Average

Source : Medium-Range Weather Forecast (ECMWF)

2.3 RAIN WATER HARVESTING SYSTEM BASIC COMPONENTS

The quality of the harvested and stored rainwater not only depends on the characteristics of the considered area, the weather conditions, the proximity to pollution sources, management of the water but also the type of the catchment area, the type of water tank (Sazakli et al., 2007).The domestic rainwater harvesting system comprised six basic components (Krishna, 2005):

i. Catchment surface: Surface that collect rain water such as roof top, the best catchment system is hard, smooth surfaces. The amount of rainwater harvested depended on the size of catchment surface, rain intensity and slope of the catchment area, material of catchement.

ii. Gutter and downspouts: Rainwater falling from catchment surface will flow through distribution systems that channel the water into container (collector).

iii. Leaf screens: The screens remove the debris, dust, leaf from the captured rainwater.

iv. One or more storage tanks: The storage tanks are most expensive component of the rainwater harvesting system.

v. Delivery system: Gravity-fed, piping and pump system.

vi. Treatment/ purification: filtration system of rainwater harvesting system.

2.4 CATCHMENT SURFACE

Catchment surfaces themselves contain a source of heavy metals and organic substances (Helmreich and Horn, 2008). There has wide variety of catchment material including metal, tile, shingle, slate, and treated wood. Roof tied with bamboo gutters are not suitable installed because of possible health hazards where zinc and copper roofs with metallic paint or other coatings are not recommended because of high heavy metal concentrations. Metal is best material consideration due to its high runoff coefficient. The different material of catchment affected the amount of rainwater collected. When calculating the amount of runoff that can be harvested from a roof. Table 2.2 shown the list of the runoff coefficient for common roof materials.

Table 2.2: Runoff coefficient for common roof materials

Material of roof	**Runoff coefficient**
Metal	0.95
Asphalt	0.9
Concrete	0.9
Tar and gravel	0.8-0.85

Source: Water Collection by Office of the State Engineer

2.5 GUTTER AND DOWNSPOUTS

The most common gutter and downspouts are half-round PVC, vinyl, pipe, seamless aluminum, and galvanized steel. Seamless aluminum gutter has generally more expensive due to its installed by professionals. The additional components include the hardware, brackets, and straps to fasten the gutters and downspout to the fascia and the wall. Gutters should be installed with slope towards the downspout, to encourage drainage away from the building wall, the outside face of the gutter should be lower than the inside face. (Dr Krishna, 2005)

2.6 LEAF SCREENS

The installation of a leaf screen to gutters can be effective in reducing routine maintenance. Leaves from the captured by rainwater will desperate flow into the tank. Leaf screens must be regularly cleaned to be effective. (Dr Krishna, 2005)

2.7 STORAGE TANKS

There are many materials and various shapes to build up a tank, it depended on the type used and the site conditions where the tanks be placed. For example, configurations can be rectangular, L-shaped and so on. Material used for storage tanks can be formed of fiberglass, polyethylene, modular storage, plastic barrels, galvanized steel, steel drums, ferro concrete, cast in place concrete and stone or concrete block. Table 2.3 below compares the advantage and disadvantage of different storage tank materials .Above ground storage tanks should be UV and impact resistant. Tanks direct by sunlight will cause inhibit algae growth and should be screened to avoid mosquito breeding inside the water tanks.

Table 2.3: Advantages and disadvantage of various tank materials

Tank Material	Advantages	Disadvantages
Fiberglas	Commercially available, alterable and moveable; durable with little maintenance; light weight; integral fittings (no leaks); broad application	Must be installed on smooth, solid, level footing; pressure proof for below-ground installation; expensive in smaller sizes
Polyethylene	Commercially available, alterable, moveable, affordable; available in a wide range of sizes; can install above or below ground; little maintenance; broad application	Can be UV-degradable; must be painted or tinted for aboveground installations; pressure-proof for below- ground installation
Modular Storage	Can modify to topography; can alter footprint and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of water tight membrane during construction
Plastic Barrels	Commercially available; inexpensive	Low storage capacity (20 to 50 gallons); limited
Galvanized Steel	Commercially available, alterable and moveable; available in a range of sizes; film develops inside to prevent corrosion	Possible external corrosion and rust; must be lined for portable use; can only install above ground; soil pH may limit underground applications
Steel Drums	Commercially available, alterable and moveable	Small storage capacity; prone to corrosion, and rust can lead to leach
Ferro-concrete	Durable and immovable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast in Place Concrete	Durable, immovable, versatile; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; permanent; will need to provide an adequate platform and design for placement in clay soil
Stone or concrete Block	Durable and immovable; keep water cool in summer months	Difficult to maintain; expensive to build

Source : Cabell Brand (2007, 2009)

2.8 NON-DIMENSIONAL DESIGN PARAMETERS AND PERFORMANCE ASSESSMENT OF THE SYSTEM

Schematic illustration of the system used in this work is shown in Figure 2.1, where R_t[L] is the rainfall, Q_t [L^3] the inflow, V_t [L^3] the stored volume, Y_t [L^3] the rainwater supply, D_t [L^3] the water demand, M_t [L^3] the main supply, O_t [L^3] the overflow, S [L^3] the tank capacity and S_{min} [L^3] the minimum water capacity. Subscript t indicates the current time step, with the assumption that all variables are always calculated at the end of each time step.

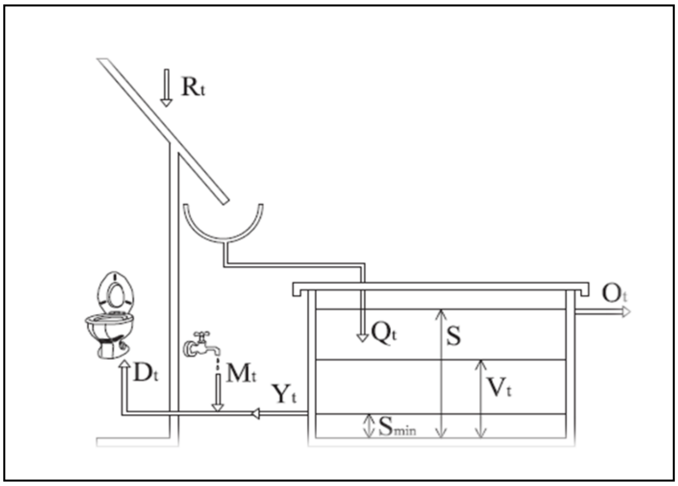

Figure 2.1: Behavior analysis model for rain water harvesting system

Source: Palla et al. (2010)

According to Palla et al., 2010 stated that the evaporation losses from the system is neglected in the mass balance equation since the tank is covered. The Q_t is calculated by following formula:

$$Q_t = \varphi \cdot R_t \cdot A \qquad (2.1)$$

Where

Q_t = volume of rainwater collected [L^3]

φ = runoff coefficient

R_t = rainfall [L]

A = overall collected surface area [L^2]

The demand fraction and the storage fraction are function of two non-dimensional parameters. The demand fraction is defined as the D/Q between the annual water demand D[L_3] and the annual inflow Q [L_3] while the storage fraction is defined as the ratio S/Q between the storage capacity of the system S [L_3] and the annual inflow Q [L_3].

2.9 DELIVERY SYSTEM

Rainwater flowed from the rooftop and through gutters and downpours to collector tank. Rain water is then forced by a pump through a flow section and transfer to the filtration system. The clean rainwater then saved in the storage tanks. Piping system involved to route the quantity of rainwater to each system. Piping system involves pipes which different diameters connected to each other by various fitting or elbows to route the fluid, valves to control the flow rate, and pumps to pressurize the fluid. Pressure drop and head loss due to the friction during rainwater flow through piping system. In addition, the friction between the fluid particles in piping system does cause a slight rise in fluid temperature as a result of the mechanical energy being converted to sensible thermal energy. However, this temperature rise due to frictional heating is usually too small to warrant any consideration in calculation and thus is disregarded (Cengel & Cimbala,2010).

The transition from laminar to turbulent flow depends on the geometry, surface roughness, flow velocity, surface temperature, and type of fluid, among other thing. (Cengel & Cimbala,2010). The flow regime depended mainly in the ratio of inertial forces to viscous forces in the fluid which called Reynolds number by following formula of 2.2.

$$= \frac{\text{Inertial forces}}{\text{Viscous forces}} = \frac{V_{avg} D}{v} = \frac{\rho V_{avg} D}{\mu} \qquad (2.2)$$

Where

V_{avg} = average flow velocity (m/s)

D = characteristic length of the geometry (diameter in this case, in m)

v = μ / ρ = kinematic viscosity of the fluid (m^2/s)

The head loss of the fluid in pipe flow is directly related to the power requirements of the pump to maintain the flow. Head loss represents the additional height that the fluid needs to be raised by a pump in order to overcome the frictional losses in the pipe. The head loss is caused by viscosity, and it is directly related to the wall shear stress (Cengel & Cimbala,2010).

Darcy friction factor where is a function of the Reynolds number only and is independent of the roughness of the pipe surface. The Moody chart or Moddy Diagram shown in Appendix D is related to the Darcy friction factor, Reynolds number and relative roughness for fully developed flow in a circular pipe.

Fluid passes through various fitting, valves, bend, elbows, tees, inlets, exits, expansions and so on via pipes. This component interrupts the smooth flow of the fluid and cause additional losses because of the flow separation and mixing they induce. These losses are minor compared to the head loss in the straight sections (the major losses) and are called minor losses. Minor losses are usually expressed in term of the loss coefficient K_L (Cengel & Cimbala,2010). The equation of total head loss in a piping system is shown in equation of 2.3.

$$h_{L,total} = h_{L,major} + h_{L,\min or}$$
$$= \left(f \frac{L}{D} + \sum K_L\right) \frac{v^2}{2g} \tag{2.3}$$

Where

D = diameter of pipe flow (m)

L = length pipe (m)

f = darcy friction factor

K_L = loss coefficient

v = fluid flow velocity (m/s)

g = acceleration of gravity (m/s^2)

Piping system involved a pump to move a fluid from one reservoir to another. The steady-flow energy equation shown in equation of 2.4.

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 + h_{pump,u} = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + h_{turbine,e} + h_L \qquad (2.4)$$

Where

p = pressure reservoir (Pa)

ρ = density fluid (kg/m^3)

V = fluid flow velocity (m/s)

g = acceleration of gravity (m/s^2)

z = elevation (m)

$h_{pump,u}$ = pump head (m)

$h_{turbine,e}$ = turbine head (m)

The head loss of a piping system increase with the flow rate. System curve is a function of the flow rate. Both the pump head and the pump efficiency vary with the flow rate, and pump manufacturers supply this variation in tubular or graphical form, as shown in Figure 2.2.

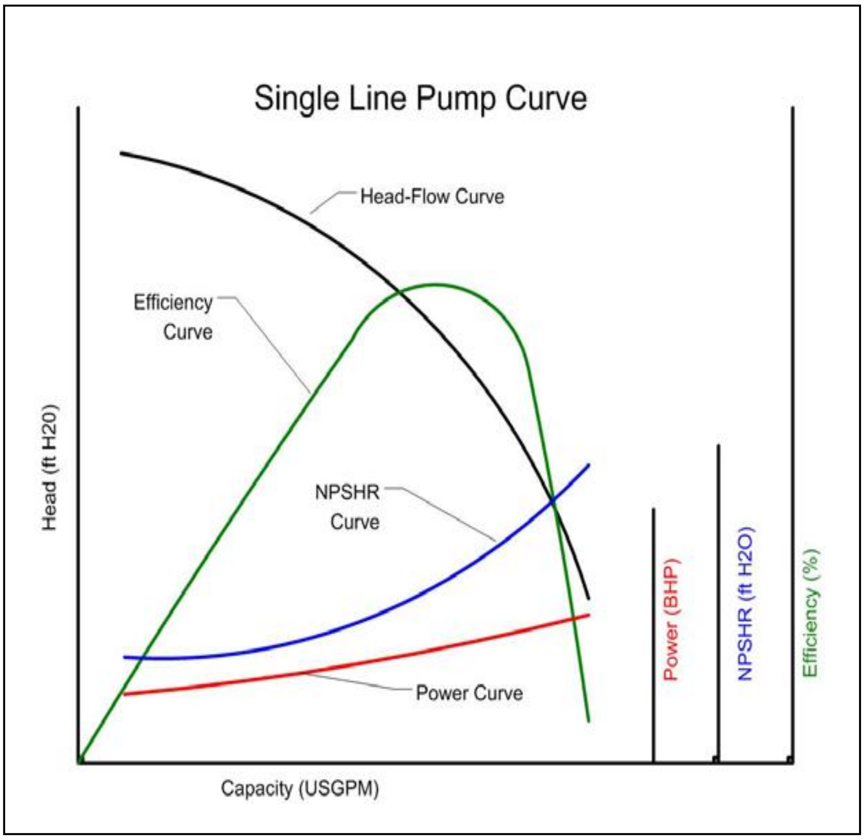

Figure 2.2: Characteristic pump curves, efficiency curve, the NPSHR curve and power curve

Source : www.greenheck.com

2.10 STUDY CASE OF RAINWATER COLLECTION SYSTEM FOR A DOUBLE STOREY TERRACE HOUSE AT TAMAN WANGSA MELAWATI, KUALA LUMPUR

2.10.1 Water Consumption

The house under study has two adults and four school going children. The house has three bathrooms. The amount of rainwater used for facilities was monitored manually installing mechanical water meters in each facility. Readings were taken and recorded manually.